From Atomic Collision to Quantum Computers

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Abstract : Quantum mechanics is amazing, and computing abilities accessible by it are just the tip of the iceberg. It has an extensive variety of applicability in biology, computer hardware. The simple idea of engineering quantum computers for commonplace use is flattering perceptible with novel technological developments in quantum theories. Quantum computing emphasizes the philosophies of quantum theory, which pacts with modern physics that clarifies the behavior of matter and energy at an atomic and subatomic level.

Quantum computing styles use quantum phenomena, on which quantum physics is based such as superposition, tunneling, uncertainty principle, and entanglement. It uses them for multiple purposes including data procedures. Hence, Quantum computing in this way fundamentally challenges tremendously tough tasks that normal computers cannot do on their own in an unconventional way which we are used to with classical computers.

In conventional computing, a bit is a term to signify information by computers. Quantum computing uses quantum bits or qubits for a unit of memory. Qubits are contained and now realized of a two-state efficient and effective quantum-mechanical system. A quantum-mechanical system is one that can be in any two different quantum states. Superposition is a principle that positions while we do not know the state of a thing at a specified time, it is conceivable that it is in all states concurrently if we do not look at it to crisscross its state. This means that energy and mass turn out to be connected to interrelate with each other irrespective of remoteness.

Entanglement and superpositioning are tremendously significant in proceeding computing and communications that can advantage us in many ways. These two marvels can be used to process an extremely big number of calculations, whereas normal computers cannot. The influence of quantum computing is amazing and not several grips the full competences it has to bid.

I. Introduction

Old-style binary computers aren't going anywhere soon. We comprehend how conventional computers work at a fundamental level. And we also discussed that it still uses the elements or components that only function because of quantum mechanics. Traditional computers do not have to concern about decoherence, the observer effect, or the no-cloning theorem, and they are not closely as sensitive to external effects as quantum devices. Therefore, they are quite impressive in the real world. They do not need ultra-super environmental environments to run. It provides us a lot of benefits. And we can achieve it by fitting CPU cores into a single chip. The data and consequences they deliver are steady for long periods in memory and on the processors without us having to worry about how the external world will impact them. There are some types of raw, rote calculations that binary computers do very well. Quantum supremacy may sidestep traditional computers one day soon, but it's tough to exhaust the stable binary computers. For this reason, we are probable to have classical computers in our lives for a long time to come.

II. Information theory, Thermodynamics, and computation

Modern information theory is founded on two significant proofs called Shannon's definition of information, and Lindauer's opinion & theory. According to their observation information is physical since it essentially continuously be encoded in a physical system deprived of which it is impossible to store,

communicate, process, or obtain information. Additionally, the information held by a physical system pays to define the state of the system. It is important to know here is that in a mathematical (and henceforth a computational) model of the laws of Nature, semantic aspects are immaterial to the interpretation problem. Shannon's well-known twin papers, A Mathematical Theory of Communication, issued in July, October 1948, put the basis for information theory. His influential contribution was to describe the idea of information precisely in mathematical form and then to contemplate the broadcast of information as a statistical wonder in a way that provided a technique to regulate the capacity of a communication channel in terms of classical bits.

As per our understanding, information can be articulated and encoded in dissimilar but equal ways without trailing its vital nature. The binary form permits suitable automatic manipulation of information. i.e. a computer needs lone manipulate modest things like integers to do astonishingly powerful information processing, from document preparation to integral calculus, to interpreting among human languages, to even imitating human intelligence.

Translation permits us to select appropriate hardware and software technologies for information processing. A legend physicist known as Shannon demarcated the vital idea of information entropy H(X) analogous to thermodynamic entropy:

$$H(X) = -\sum_{i=0}^{N-1} p_i \log_2 p_i,$$

which delivers a way to guess the average minimum number of bits desirable to encode a string of symbols, founded on the frequency of the symbols or the probability p_i of its appearance. However, Shannon entropy does not measure the degree of correctness, but it measures the degree of the decadence of a system.

Over-all, a complex set of instructions can be condensed to n binary picks. We then have a prepared measure of the information content of the object by merely including the number of binary selections or the state of n binary bits. The state of a binary bit, by preceding arrangement, can be randomly mapped to the binary substitutions, such as 0 for spin-down of an electron and 1 for spin-up. We can, therefore, use the bit as the unit of information and measure the information content of an information resonant object as the scope of the set of orders needed to rebuild the state of the object.

In 1961, Rolf Landauer, introduce a very important concept through his seminal paper on reversible computing. Which provided an extraordinary vision to the world. According to him, since information is physical, a fact lately confirmed experimentally, the laws of physics necessarily, therefore, place bounds on information processing whether classical or quantum. He insightfully twisted to thermodynamics and showed that only logically irreversible operations that cause information loss would able to expend energy. He displayed that there is an important asymmetry in the way Nature processes information. Further, he demonstrated the counter-intuitive outcome that all, but one, a process essential in computation could, in theory, be made reversibly without dispelling heat. For instance, copying classical information can be completed reversibly and deprived of losing any energy. However, when information is removed there is a minimum energy cost of kT ln 2 per traditional bit (about 3×10^{-21} joules at room temperature) to be paid, where k is the Boltzmann constant, and T is the absolute temperature in Kelvin of the computer's environment. The removal of information is unavoidably gone together with the generation of heat. After a system experiences an irreversible action, its previous history, unless archived, is irreversibly vanished.

Landauer visualized computations as engines of changing free energy into left-over heat and mathematical work where deletion of information unavoidably central to heat production. Landauer's theory and the second law of thermodynamics can certainly be understood as the logical importance of the fundamental reversible laws of physics. The law has multiple uses across thermodynamics and quantum mechanics for instance, this is usable in the typical Hamiltonian formulation of mechanics and in the unitary

time evolution. Landauer's theory attaches physics with information theory. The joining directed individuals to the reason for energy-efficient algorithms at a time when reducing algorithmic intricacy was the fad.

What is extraordinary about Landauer's principle is that though computation is a non-concrete mathematical procedure, charting one set of input bits into an extra set of output bits. It is not at all understand that there occurs an important joining among such a charting and microscopic motion related to heat. It, certainly, seems extraordinary that the rational reversibility of computation (i.e., inputs can be contingent from the outputs) also suggests physical reversibility. The key to physical reversibility is to erase with a copy. That information is adaptable to energy has been experimentally revealed.

Before Landauer's published paper, it was usually expected that deterministic computation is not essentially logically reversible and characteristic programming is improbable to be so. Lecerf (1963) and Charles Bennett (1973) exhibited that deterministic computation would be simulated through a rationally reversible Turing machine. This means it is likely to reprogram any deterministic computation as an order of logically reversible phases, on the condition that the computation is permitted to save a copy of its input. Bennett additionally recommended computing with nucleic acids or DNA to realize physical reversibility.

By equivalence with thermodynamics, one may settle that Information that has not been compressed to disclose a valuable interpretable pattern is a random information, which on average does not produce valuable knowledge in a human mind. In this regard, molecular biologists encounter a severe issue. Till they discover, a theory to produce a given DNA sequence, the only way to interconnect comprehensive genetic information to another is to direct the whole DNA sequence. Whereas, the equations of physics have repeatedly advanced in the direction of compression to an astonishing degree. Physics is coded and quantifiable information.

III. Spin and Qubit

To understand the fundamentals of quantum computers it is required to have a better knowledge of spin, the nature of fundamental particles, their states, and some theories associated with them. However, if you want to skip this section you can, after having a look at below two paragraphs. But the recommendations are you go through them. Broadly, we are going to cover the below concepts in the next three sections.

1.	Spin	Spin is the whole angular momentum, or essential angular momentum, of a form or body.
2.	States	A quantum state in quantum physics describes the state of an isolated quantum system. Also, a quantum state delivers a likelihood spreading for the value of each observable, i.e. for the result of each likely measurement on the system.
3.	Charges	Quantum theory explains that charge is a numerical consequence, but only in combination with a space in which the element occurs.
4.	Fundamental particles	In particle physics which is a branch of physics, an elementary particle or batter fundamental particle is known as the subatomic particle with no substructure. Therefore, it is not unruffled by other particles. The total number of fundamental particles is 12.
5.	Quantum numbers	A quantum number is a number which happens in the theoretic countenance for the value of some quantized property of a subatomic particle. The example of the beforementioned particles is an atom, or molecule which can solitary able to have convinced integral or half-integral values.

6.	Atomic Theory	In the world of chemistry and physics, atomic theory is known as a scientific theory that explains the nature of matter. It also explains that matter is fundamentally a collection of discrete units called atoms
7.	Schrodinger wave equation	The Schrödinger equation is termed as landmark "equation". Basically, in terms of mathematics, it is a simple linear partial differential equation that defines the behavior wave or state function of a quantum-mechanical system. It can be better understood in connection with potential and kinetic energy.
8.	Wave function	A wave function in quantum physics is a scientific explanation of the quantum state of an isolated quantum system.

Table 1

Qubits are signified by the spin (up, down) of electrons or the polarization of photons. Spin and polarization have properties that are quite different from their classical corresponding item which is traditional computation. In QC to measure spin, we must select a direction and then measure it (spin) in that direction. As we know the spin is quantized. When we measured, it provides two likely answers. Those answers are not a continuous range of answers. We can assign classical bits to these outcomes. For instance, if we acquire an N, we can contemplate it to be the binary digit 0, and if we get an S we can ponder it to be the binary digit 1. This is precisely how we get answers from the quantum computation. The latter phase of the computation is to take a measurement. The outcome will be one of two things, which will be understood as either 0 or 1. While the real computation will include qubits, the concluding response will be in terms of classical bits.

Quarks come in different types. The dissimilar types of quarks in common teams are called flavors and colors. The "flavors" are maybe up, down, charm, strange, top, and bottom based on the "state" (refer figure). The colors spreads are red, yellow/green, or blue. So, if you want to explain to your friend, what type of quark you have … precisely - you can tell him that you have a red down quark (in practice however it is not possible). The same is true if you want to give him information about antiquarks, e.g. you kept an anti-yellow anti-top quark. Now take the example of Meson which contains two quarks of color and an identical anti-color, but they have dissimilar flavors. Baryons, for example, have three quarks which are always of three different colors, but a variety of flavors. But it seems no tangible agreement yet at least on superficial ground…therefore to understand the origin and composition of atoms, their mass and likewise to our world in a concrete way. Refer to figure 1 for SM.

COMMENTS	LEPTONS		Quarks		Remarks
Mass Particles Ordinary particles belong to this group	**Electron** Electric Chare = -1	**Electron Neutrino** No electric charge and no mass (possibly)	**Up** Electric charge +2/3 , Proton 1 , Neutrons 2	**Down** Electric charge - 1/3 , Proton 1 , Neutrons 2	**Each particle has been complemented by an anti-matter. Just like, mirror image.**
Existed just after Big Bang , rediscovered in CERN	**Muon** Havier then electron. It lives for millionth of a second , charge +/- 1	**Muon Neutrino** No electric charge, created along with Muon	**Charm** Electric charge +2/3 , Havier then up	**Strange** Electric charge - 1/3	
	Tau Very Unstable , charge +/- 1	**Tau Neutrino** No electric charge	**Top** Electric charge +2/3	**Bottom** Electric charge - 1/3	

Force Particles	Gluons	Photons	Bosons	Gravitons
These particles are responsible for four fundamental forces of nature	Transporter of Strong force – The explosive release of nuclear energy is the result of strong force	Building block of light and carrier of electromagnetic force. The disciple of chemistry , magnetism are the results of this.	Transporter of weak force. Some form of radio-activity are the result of weak force.	Transporter of gravity. Experience of Wight is the byproduct of gravitons

Figure1: The Standard Model

The fundamental quantum particles are made up of all other subatomic particles. For instance, each proton is constructed by two up quarks and one down quark. A neutron is created by two down quarks and one up quark. Whereas the electron, as an elementary particle, is not made up of anything. It's an electron, with no additional subatomic particles to add up or break it down into. But electrons, protons, and neutrons make up atoms, atoms construct elements and molecules, and so on.

Each rudimentary quantum particle has a mass, charge, and spin. A *charge* is the quantity of current as compared to an electron. For instance, an up quark has two-thirds of an electron charge and a down quark has a negative one-third of an electron charge. Because a proton has two up quarks and one down quark, this means the proton has a 3/3 (2/3 + 2/3 – 1/3) charge of an electron, or precisely equal to one electron. In atoms, the number of protons in the nucleus equals the number of orbiting electrons for this reason.

Elemental particles have *spin*, which relays inversely to the numeral of revolutions a particle essentially style to return to its original orientation. All elemental particles have a spin of one-half, which means they essentially rotate twice to return to their initial orientation. Quantum charges and spins are important to quantum computers because the responses that quantum computers give us are often a consequence of charges and spins. Dissimilar quantum properties and states are cast-off to deliver answers in different types of quantum computers. Let's understand it a bit deeper because it is important. We will cover the spin, charges, and state of the particles in the next section.

IV. Qubit and electron states

As mentioned above, in the atom model, the electron can exist in either the 'ground' or 'excited' states, which we'll call |0> and |1>, individually. By putting light on the atom, with suitable energy and for a proper length of time, it is conceivable to change the electron from the |0> state to the |1> state and vice versa. But more fascinatingly, by dipping the time we shine the light, an electron originally in the state |0> can be moved 'halfway' between |0> and |1>, into the |+> state.

V. Electron Spin Theory

The electron spin theory defines the electron as a quantum particle in its place of the meek sphere as in the classical theory. The quantum philosophy says that the electron spin direction and its effect on the convinced possessions like magnetic properties of the atom. The spin up and spin down the path are equal to the spinning in the +z or –z-direction. These spins are associated with the particles that contain spin s equivalent to 1/2, i.e. for electrons.

In quantum theory, the electron is made up of the tiny magnetic bar and its spin points to the north pole of the minute bar. If two neighboring electrons have a like spin direction, the magnetic field is formed by them which strengthens each other and therefore a robust magnetic field is expanded. If the adjacent electrons have an opposite spin direction, the magnetic field is formed by the call off each other and no magnetic field is existent. If the nearby electrons have an opposite spin direction, the magnetic field formed by them removes each other and no magnetic field is present.

VI. How to make robust quantum Computers: welcome quantum error correction

As per the present informal agreement among the experts' 72 qubits and beyond quantum supremacy could be achieved. However, the biggest challenge to achieve quantum supremacy is early qubit decoherence. As we know, decoherence is a quantum particle's states going from its easy-to-see superposition to its settled, measured, single, classical state before all the ensuing entangling brands receiving useful information. Once decoherence has occurred, premature or not, it cannot simply be inverted. With "faultless" quantum computers, decoherence would occur only and precisely at the point where a "response" is desirable and measured. It would always be on purpose.

For an ideal quantum computer, a qubit would stay in its cohered state if it is desirable for the quantum calculation and then, and only then, decohere when measured. How long the qubit will stably maintain the state of the qubit is called its coherence time. It is every so often measured in milliseconds, but some quantum computer types can last seconds to many minutes. The first instruction of business for most quantum computer makers is to increase coherence time. Increased coherence time means fewer errors and more time to compute and return answers.

The current fact is quantum computers are filled with premature quantum decoherence and just absolute errors. Both can happen because of qubit building, high temperature, contamination, sound, vibrations, faulty gates, faulty measurements, defective initial state groundwork, background nuclear spin, and countless other events.

It's not just a race for adding new qubits, but a race for adding error-tolerant qubits, and then evaluating the progress of technology requires benchmarking both metrics. The current goal is a 0.5% coherence rate. At those levels, computational power is expected to increase exponentially. The growth of performance decreases significantly at higher error rates, and beyond 1% error rates adding more qubits does not add any computational power at all.

Any contact with the external world is a hazard. Dipping errors and noise is the number-one quantum challenge and has produced a field that has its name, quantum error correction. Error correction is tryingto use a group of dissimilar arrangements, including both quantum and classical methods. No one has achieved it yet, but every quantum computing vendor is trying. Error rates are typically reported as a ratio of quantum operating time to decoherence time.

The quantum error threshold theorem grasps that any quantum system that modifies errors faster than it makes them is practical. As the number of qubits upsurges, so too does the natural error rate. For quantum computers to be very beneficial, the error rates need to be below 1 percent precisely below 0.002 percent. As a comparison, a traditional CPU can do trillions of calculations short of an error.

In the quantum world, we are just eager to contract the error rate down to one error per thousand calculations. Attaining that, sideways with some good error correction, will permit some serious quantum work. Till now we are searching for this with no tangible result.

However, the efforts are on. Quantum computing experts are trying to decrease quantum errors by recognizing and fixing the most important rate-limiting components or issues. Common answers comprise refining coherence times, stringently isolating quantum components from the outside world, utilizing supercooling, check qubits, growing the presentation of other components to outdo the errors, and using quantum entanglement as error correction.

As we discuss in some time there are several dissimilar types of collaboration and integrations required to make the quantum initiative a success for corporate, government, or holistic research. But it does not end at this point, there are several additional features of the quantum computer are also important to make QC efficient and usable. For instance, Calibration Errors actions how well the electronic controls for software design and measuring qubits are standardized to guarantee precise procedure and error resolution. Whereas, circuit Optimization takes care of how well an optimizing compiler recovers the plan and acts of a circuit across its penetration and qubit register breadth. Coherence, as discussed, is significant for how the qubit stays in an operational state. The coupling map tells us how qubits are linked and the actions of how qubits are associated with other qubits and in what patterns. Qubit crosstalk is providing "insight" about how the state of one qubit marks nearby qubits. And, gate fidelity is the error rates that gate processes to move qubits from their present state to new states.

As these are the important aspects of quantum computing so let's discuss a few of them in a bit of detail. This cannot be a race to add qubit quantity. IBM has proposed a metric called Quantum Volume that scales with both error tolerance and qubit count (Figure 2). It reduces errors as qubits are added. In other words, the reduction in errors is as important as the addition of computing power.

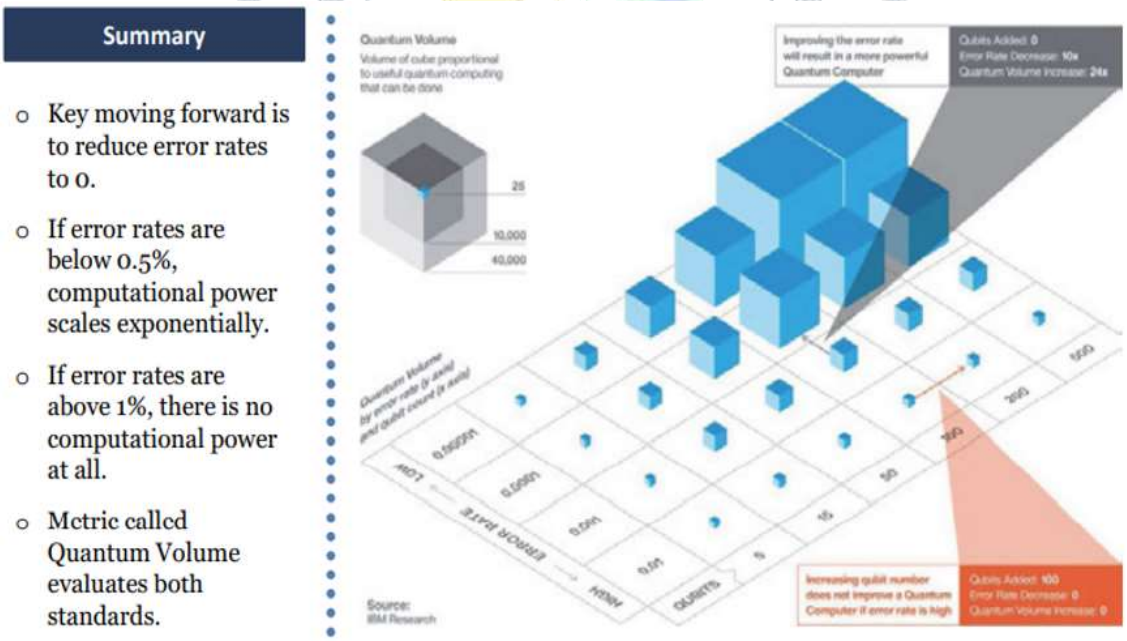

Figure 2: quantum volume

- **Refining Coherence Periods**: is one of the techniques of error rectification. It helps to advance the quality and control of each qubit's cohered state to be lengthier than the desirable calculation time. It can achieve it by improving whatsoever is the error-limiting component of the quantum computer. Such as quantum gate sound or connectivity speed. As we know, the longer the qubit can stay cohered, the fewer errors it is probable to have.

- **Surrounding Separation:** Computer scientists have known the benefits of operating computers in controlled surroundings that isolate them from the immoderations of the outdoor world. This is not a new phenomenon and even applicable to classical computers as well. At least in its initial days. That's the reason all computer rooms are temperature-controlled (heat is the enemy of all computer components), air-filtered, humidity-controlled, cleanser environments.

  You don't find a lot of computers running very long left in the outdoor world unprotected from normal weather and events. But most of today's classical computers have mellowed physically to a point where they can live operating in normal weather environments, except they are bare to truthfully extreme conditions. For instance, the most general types of computing devices in being work every day in the real world. Most laptops, pad devices, and personal computers function fine outdoor in a very controlled computer room.

  Quantum computers are not there yet. They are still very delicate machines and essentially be protected from not lone weather extremes but even very usual conditions. Most of them function most proficiently by running (at least the quantum components) in specific types of weather extravagances, such as very cold temperatures. They essentially are protected against radio waves, normal circumstantial radiation, electromagnetic interfering, brash noises, and vibrations. But most quantum experts do imagine a day when, as is the situation with classical computers, quantum computers will be constructed in a way so that they are ample resilient and in less requirement of different environmental isolation.
- **Supercooling:** Most quantum computers essentially supercool their qubits (and other nearby components) to near zero degrees Kelvin. Which is near –460F to minimalize early decoherence issues. Heater temperatures are exposed to permit more errors and to produce more unwelcome stray quantum particles with nearly all the quantum computer technologies, even with the few kinds that allegedly don't require ultra-cool temperatures. They may not "want" super cold temperatures, but even they appear to do better with fewer errors in lesser temperatures. Therefore, qubit chips and closely related apparatus are supercooled using outside cryogenic or dilution refrigerators.

  Till now absolute zero (0K) is not achieved. Also, at absolute zero all particles' energy and momentum would be at a standstill to the bare minimum physical conceivable (something called zero-point energy). At absolute zero, most moving and even solid-state gears would flop to function as usual. With that said, the quantum computer of the upcoming is likely to be able to endure advanced temperatures, perhaps equal to the necessities of today's classical computers, because necessitating supercooling is expensive and restrictions where and how they can be used.

  But for now, lower temperatures typically advance coherence times and do a reduction to errors. Lower temperatures also produce a quantum property called superconductivity, which is zero or near-zero electrical confrontation in things cooled below critical temperature thresholds. Superconductivity upsurges electron flows and permits stronger electromagnetic connections. Many quantum computers use superconductivity to create their qubits, and it is cast-off in many other applications, such as superfast maglev trains, medicinal gear, and super-strong magnetics.

Repetitive Calculations: One way to contest errors is to run a similar calculation at least three to four times and store the outcomes in the classical world. After running the same calculation many times, the computer will look at all the kept results and, if there is a difference, take the outcome that seems more than the others. Though this error correction technique also decelerates the computer down in direct relation to how many duplicative processes are used, and there is no guarantee that the furthermost signified answer is the right answer.

- **Using Quantum Entanglement for Error Correction:** In the traditional computer world, if a lot of faults are to be expected, a bit's value can be derivative and stored to one or more "backup" bits at the identical time. If there is a difference among bits, then the most popular value is taken. But in the quantum world, since of the no-cloning theorem and the observer principle, qubits cannot be copied directly while in their quantum states. In its place, entanglement can be cast-off to produce indirect copies, although entanglement promises are subtle and easy to lose track of as decoherence happens.
- **Check Qubits:** Additional error correction technique usages extra qubits as check qubits, which is like how to check bits are cast-off in the classical binary world. The check qubits are applied in some sort of logical inspection method, which notices errors and aids to correct them. For instance, an extra check qubit is used to guarantee that the subsequent qubyte adds up in a specific way. For instance, the computer can add a 0 or a 1 to the check qubit location of the qubyte to brand sure the sum of all qubits ends up as an even value.

  If the quantum computer notices an adverse sum inveterate from a qubyte sum, an error can be acknowledged and the quantum operation can be recurrent. You might be familiar with a like general error correction traditional technology called Redundant Array of Independent Disks (RAID) in the binary computer world. The big problem with this sort of simple even-or-odd checking is that there is no way to guarantee that errors don't occur in a way that isn't noticed only by even or odd values. But it's improved than nothing and more complex, but similar error-checking situations have been used to make our current binary world extremely reliable. Quantum computer manufacturers are using quantum error-checking approaches to make quantum computers more dependable. Error-checking qubits added to a system only to deliver fault tolerance are recognized as ancillary (or ancilla) qubits. Quantum computer vendors are even now besieged to make the best use of the number of qubits, so partaking to "left-over" some to deliver error checking isn't best. Right now, the present state of several quantum computers and devices is that it desires many, many ancillary qubits to ensure one stable qubit. The number of ancillary qubits desirable to make one stable qubit has been measured from a few up to millions. That's a strange range and scaling problem. Still, occasionally the best performance that can be attained includes adding more qubits and using them as ancilla. But all vendors look headlong to the day they can diminish ancillary qubits.
- **Increase Performance of Other Components:** A applied way to conquest decoherence errors is to upsurge gate, connectivity, and state groundwork. By decreasing the time, it takes to calculate a quantum outcome and read it, the wanted computation and subsequent value read can be done before an error makes the qubit hurriedly decohere. For instance, let's suppose that a quantum computer has a load of decoherence errors that jolt trendy around 100ms. If computations can be finished in below 100ms, then that quantum computer can circumvent the nastiest effects of decoherence and get more precise consequences.

  Nowadays, several of the qubits are probable to be involved in error correction. The complete performance of QC hangs on a diversity of some other additional factors, such as gate preparation, connectivity between gates, error correction, and read performance. Even when several qubits and error correction rates are identical between quantum computers, they may be different types of quantum computers made to solve different types of problems. Therefore, any direct judgments grounded on qubits alone are foolish. It is very difficult to say that a 90-qubit computer must be better than a 60-qubit computer, particularly for all types of problems.

VII. Conclusions

Quantum computation is possible with neutral atom qubits. Quantum simulation and Rydberg dressing are replacements to circuit founded quantum computing for reconnoitring many body quantum

dynamics are available. Quantum computers are extremely subtle: heat, electromagnetic fields and collisions with air molecules can reason a qubit to misplace its quantum properties. This process, known as quantum decoherence, reasons the system to bang, and it occurs more rapidly the more particles that are complicated. Quantum computers need to defend qubits from outside interference, either by bodily isolating them, keeping them cool or zapping them with carefully measured pulses of energy. Additional qubits are needed to correct for errors that creep into the system.

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